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Keywords: clusters; knowledge transfer; social networks; patenting

JEL Classification: L11; M13; O53; R12

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Geographic clustering and network evolution of innovative activities: Evidence from China's patents

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Abstract

This study examines the spatial distribution and social structure of processes of learning and knowledge creation within the context of the inventor network connecting Chinese patent teams. Results uncover mixed tendencies toward both geographic co-location and dispersion arising from combined processes of intra-cluster learning and extra-cluster networking. These processes unfold within a social network that becomes less fragmented over time: as a giant component emerges and increases in size, social distances among inventors become longer. The interplay between geographic and network proximity is assessed against China's institutional environment. Implications of the findings are discussed for regional development and policy-making.

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Section 1. Introduction

Empirical research has long investigated the mechanisms and processes that promote the co-localisation of economic activities (Audretsch and Feldman, 1996; Braunerhjelm and Feldman, 2006; Krugman 1991; Marshall, 1920). Much of this work has focused on agglomeration economies whereby he benefits a firm can derive from being located in a particular region increase with the number of other firms in that region (Krugman, 1991). In a similar vein, the fact that geographic concentration also occurs in high-technology industries has been explained in terms of localized knowledge spillovers. For instance, being close to key star inventors was found to play an influential role in the creation and location of new biotechnology firms in the US (Zucker and Darby, 1995). Similarly, the tendency of high-technology start-ups to locate in proximity to other established firms in their industry has been explained in terms of knowledge externalities (Jaffe et al., 1993).

More recently, there have been attempts to combine insights from economic geography and social network analysis to shed new light on the tendency of innovative activities to concentrate geographically (Sorenson and Stuart, 2001; Stuart and Sorenson, 2003). Much of this work contends that, in addition to agglomeration economies, social networks shape the geographic distribution of innovative activities. In this view, activities tend to arise in close proximity to industry incumbents because they can leverage on the geographically local social ties that offer the necessary resources and knowledge (Sorenson, 2003). Similarly, it has been shown that the proclivity of US venture capitalist firms to invest in spatially distant targets is mitigated by the structure of the co-investment network in which the firms are embedded (Sorenson and Stuart, 2001). Other studies have broadened this perspective to include in their analyses not only the spatial distribution of activities and their structural positions in the underlying social network, but also their institutional characteristics. For instance, it was shown that it is the interaction among network position, geographic distance, and organizational form that matters in the flow of information and performance of the biotechnology firms in the Boston community (Owen-Smith and Powell, 2004).

This article takes a step in this direction, and explores the combined role of geographic distribution, network structure and evolution, and institutional demography within the context of China's emerging market in patenting activities. To this end, we construct and study the inventor network connecting teams of scientists working on Chinese patents between 1976 and 2006. Drawing on this dataset, we investigate how tendencies toward internationalization and geographic clustering combine to characterize the geographic and social contours of China's innovative activities. Moreover, the article draws on China's distinct institutional characteristics to account for the evolution over time of the geographic distribution of innovation in China. A special emphasis will be placed on one aspect of the institutional environment that is likely to affect the transfer of high-technology knowledge: whether it is a closed proprietary-dominated environment where there is more protection against leakages of information, or an open environment where spillovers are more likely to occur. The orientation toward control over information explains why proprietary environments tend to foster linkages between companies, whereas open environments are associated mainly with universities and the ethos of open science (Powell et al., 2009). We draw on these and other institutional features (e.g., the strength of intellectual property rights (IPR) and the availability of institutions with networking capability) to shed light on the different path followed by Chinese companies and universities in forging ties across the geographic space.

We locate our study within the debate on the importance of geographic and social proximity. However, our work differs from other empirical studies for three main reasons. First, unlike other analyses (e.g., Giuliani and Bell, 2005; Sorenson and Stuart, 2001), we do not investigate distances at the node level (e.g., firm, scientist), but adopt a global perspective and examine their evolution at the system's level. Second, we study how the tendency toward clustering can combine with an opposing tendency to interconnect with extra-cluster sources of knowledge, for instance through the establishment of international linkages (Lambiotte and Panzarasa, 2009). This enables us to assess the extent to which China as an emerging market is catching up in innovative capability by reconciling the incentive to reap the benefits deriving from geographic clustering against a need for access to resources located at leading-edge centers of technological development. While agglomeration economies, such as knowledge spillovers, may induce innovative activities to locate close to one another, the availability of social ties and the necessary resources only at distant locations may pull in the opposite direction, and lead to geographic dispersion.

Third, we examine associations between the topology and geography of China's innovative activities, by looking at how intra- and extra-cluster knowledge flows are reflected by the underlying structure of the evolving social network that connects Chinese inventor teams. We study the connectedness of the network over time, looking at the emergence and development of a giant component, and the evolution of social distances among inventors. The article sheds light on the complexity of the relationship between network and geographic measures of distance, and how this relationship translates into a distinctive pattern for the spatial distribution and topology of China's activities. The emergence of this pattern is examined as a possible response to China's institutional weaknesses in social infrastructure, such as inadequate enforcement of IPR and lack of strong governance mechanisms that facilitate social networking functions.

The rest of the article is organized as follows. Section 2 locates our study within the literature and discusses the debate on the relationship among knowledge transfer, interactive learning and different types of proximity. Section 3 assesses China's innovative capabilities in the context of the National Innovation Systems (NIS) literature, by looking at its scientific publications, R&D expenditures, skill base and institutional infrastructures necessary for innovative activities. Section 4 introduces the data consisting of Chinese patents, and describes how the inventor network was constructed. It then outlines the methods used to measure various geographic and social distances in this inventor network. Section 5 presents the results, and Section 6 summarizes and discusses them in terms of their implications for knowledge transfer and regional development in China's emerging market.

Section 2. Knowledge, interactive learning, and proximity

One of the main areas of investigation in economic geography is concerned with the relationship between geographic proximity and its impact on innovation and interactive learning (Audretsch and Feldman 1996; Jaffe et al., 1993; Krugman, 1991). Innovative activity is knowledge intensive. Despite the fact that knowledge in principle should be able to move inexpensively through space, a number of empirical studies have documented that knowledge production has a distinctive geography (Bathelt et al., 2004; Braunerhjelm and Feldman, 2006). For instance, in biotechnology and financial services, high-technology and innovative economic activity tends to be geographically clustered (Owen-Smith and Powell, 2004, 2006). This tendency has increased over time despite attempts to disperse it (Gertler, 2003; Braunerhjelm and Feldman, 2006).

The literature highlighting the benefits of spatial proximity has suggested the following arguments: 1) with short distances it is easier to have face-to-face interaction, and this becomes crucial especially for the transfer of tacit knowledge (Gertler, 2003); 2) spatial proximity facilitates cognitive proximity, such as the generation of shared social norms, heritage or jurisdiction, which in turn helps people understand one another (Boschma, 2005); 3) spatial proximity increases the likelihood of unanticipated encounters between key players, often referred to as local buzz (Storper and Venables, 2004), local broadcasting (Owen-Smith and Powell, 2004), noise (Grabher, 2002) or 'being there' (Gertler, 2003); and 4) spatial proximity increases the likelihood of knowledge spillovers favoring the economic actors located close to the innovative activity (Jaffe et al., 1993; Audretsch and Feldman, 1996).

Other studies, however, have suggested a weakening link between spatial proximity and learning. First, the idea of localized learning and spillovers has to contend with the debate about the lessening impact of geographic distance on knowledge transfer – the “end of geography” or “death of distance”, in popular coinage (Cairncross, 1997). Due to the increasing communicability of knowledge, research has suggested that it becomes increasingly feasible to carry out many types of economic activities in different locations (Morgan, 2004). A further argument stresses the need to take into account other forms of proximity that differ from geographic proximity (Lambiotte and Panzarasa, 2009). Boschma (2005), for example, argues that geographic proximity cannot be examined in isolation, but must be assessed in conjunction with other measures, such as cognitive, organizational, social, and institutional proximity. In the same vein, research has suggested that within trades or professions the links that play a key role tend to be different from purely geographic connections. For example, communities of practice or epistemic communities are relevant determinants of knowledge creation and transfer (Brown and Duguid, 1991; Amin and Cohendet, 2004).

Despite agreement on the relevance of a notion of proximity that extends beyond simple geographic considerations, there is still little understanding of how different forms of proximity combine with one another to affect economic activities. For example, it remains unclear how the transferability of different types of knowledge depends on distance, and in particular to what extent tacit knowledge requires local geographic proximity, whereas codified knowledge is able to travel over long distances without cost (Gertler, 2003). It is a difficult task to map the geography of knowledge as the impact of geographic proximity is not usually direct, but is mediated by relational proximity associated with the formation of organizational routines and social practices (Sorenson, 2003). Moreover, it is difficult to uncover localized knowledge transfer and sharing and there is ‘no understanding of the way in which spillovers occur and are realized at the geographic level’ (Feldman, 1999 p.8).

Empirical research on the formation of intra- and extra-cluster knowledge flows among actors in an innovation system is sparse (Breschi and Lissoni, 2001; Giuliani and Bell, 2005). Moodysson et al. (forthcoming) have charted local and global knowledge flows, and looked at the spatial organization of innovation and agglomeration and interaction in local clusters and their connection to global networks. Evidence indicates that interactions within geographic clusters can be occasional and perfunctory, and that most inter-firm transactions do not take place within clusters (Amin and Cohendet, 2004; Malmberg and Power, 2005). Instead, research has shown that firms, for many reasons, tend to establish trans-local relationships with one another, typically in the form of R&D partnerships, commercialization and investment arrangements, and licensing deals (Owen-Smith and Powell, 2004). Moreover, much valuable knowledge creation and exchange take place precisely along these deliberately constructed channels of communication, exchange, and co-operation. These linkages connecting geographically distant economic units highlight the importance for knowledge-creation and learning of the linkages that clusters establish with extra-cluster sources of knowledge (Bathelt et al., 2004; Giuliani and Bell, 2005; Maskell et al., 2006).

Despite their documented frequency, however, links spanning across geographic boundaries still remain weakly theorized in the cluster literature (Bathelt et al., 2004 p.56). On the one hand, it has been shown that social networks matter as face-to-face interactions between knowledge workers are necessary to transfer knowledge assets that defy codification (Gertler, 2003; Sorenson, 2003). On the other, however, it still remains unclear what type of interaction is required. For example, it is debatable whether interaction needs to occur repeatedly over time, thus requiring co-location, or instead needs to take place frequently and on a face-to-face basis only within an initial limited period of time, while subsequently becoming more scanty and occurring thorough other means of communication, such as tele-conferences or e-mails. Similarly, it remains unclear whether indirect interaction through reported conversations is enough to diffuse knowledge to different network members (Maskell et al., 2006).

A further dimension in the debate on the role of proximity is the distinctive institutional environment which affects tendencies toward geographic clustering or internationalization. For example, it has been documented that, in the US biotechnology inter-firm network, tie formation occurs between geographically distant nodes as a result of the intermediation of venture capital companies (Owen-Smith and Powell, 2004; Sorenson, 2003; Sorenson and Stuart, 2001; Powell et al., 2009). Institutional ownership also affects the geographic distribution of activities. In this respect, Powell et al. (2009) and Owen-Smith and Powell (2004) point to the distinction between the open-science environment, fostered by publicly-funded research institutes, non-profit organizations, and universities, and the environment dominated by private commercial organizations, where a more protected and proprietary transfer of knowledge tends to occur. There are two possible arguments that relate institutional ownership to the tendency toward clustering or internationalization. The first centers on the absorption of spillovers within a given geographic area (Jaffe et al. 1993). According to this argument, since activities co-locate to absorb spillovers from knowledge transfer, then geographic clustering is more likely to occur precisely when the institutional environment is more open and enables information to flow and spillover more freely. Conversely, the counter-argument suggests that environments dominated mainly by universities or publicly-funded organizations, with an ethos of open science and non-proprietary communication flows, are more likely to extend geographically because they are not constrained by the possibility of leakage of proprietary information (Owen-Smith and Powell, 2004).

Section 3. China's innovation environment

The NIS perspective (Dodgson 2009; Nelson 1993) focuses on how national institutions of finance, education, law, science and technology, corporate research activities and government policies combine to influence innovation (Nelson, 1993). In addition, a more relational approach (Lundvall, 1992) examines the impact of business and social relationships on innovation with an emphasis on the social embeddedness of learning. Government policies and regulatory systems are also regarded as crucial factors governing IPR and standards. It is argued that innovation is more frequent and effective when the broader environment includes well articulated and coordinated elements (Dodgson, 2009). This article assesses elements of China's NIS and estimates the extent of technological catch-up with the West as well as the areas that remain less developed.

Most studies of high-technology clustering have been carried out for developed countries hosting the centers of leading-edge technologies, particularly the US. (Braunerhjelm and Feldman, 2006; Powell et al., 2009). For the US new knowledge in high-technology industries tends to be developed first within regional agglomerations before diffusing through constructed networks further afield (Owen-Smith and Powell, 2004). However, emerging markets, such as China, have not been at the leading edge in the development of the most recent high technologies. Thus, our argument is that the construction of networks in China has been as much concerned with absorbing new knowledge from abroad through the creation of networks and pipelines as with the establishment of regional agglomeration.

This article outlines an assessment of China's resources in the science base and skill levels, its infrastructure necessary for innovation purposes, its institutional environment, and the role of universities and companies in innovative activity. Our argument is that, although China has made enormous leaps in extensive terms through numbers of patents and publications, it lacks some of the infrastructure and especially institutions that facilitate networking for innovation purposes. In assessing the roles of geographic and social proximity in knowledge transfer, we should take into account China's institutional environment that is not as favourable to building these structures as in the US. We also make some comparisons with the NIS in Taiwan, with an emphasis on the infrastructural features, as policies in Taiwan over the last twenty years have been particularly concerned with some of the perceived NIS deficiencies in emerging markets.

China has vastly improved in recent years in terms of its science base. A clear indication of this is given by the surge in numbers of patents and scientific publications. Patenting has grown from virtually zero in the late 1970s to 430 patents per year by 2002. This is well behind Taiwan, with 6,000 patents per year, and is miniscule compared with the US (90,000 per year) or Japan (35,000 per year). Despite this, China's growth, in the same way as India's, has been much higher than for other emerging markets. Its R&D expenditure has also increased but still stands well behind that of the US and Taiwan (Government R&D GERD/GDP of 1.34 compared with the US's 2.61, Taiwan's 2.52 or the OECD average of 2.25, and Business R&D BERD/GDP of 0.91 compared with the US's 1.84, Taiwan's 1.69 or OECD average of 1.53) (OECD Main Science and Technology Indicators 2007).

Likewise, scientific publications in China have greatly increased over the last ten years, although the growth is still quite small if compared with the US's. The number of scientific publications produced by China between 1999/2001 and 2002/2004 increased from 55,000 to 91,000, putting China well ahead of Russia, India, Brazil and the Asian Tigers, although these figures are dwarfed by the number of scientific papers published by the US (above 750,000 per 3-year period). China's specialization of scientific publications is above the world's average in engineering and technology, although the impact of its publications remains below the world's average levels in all other areas (Athreye and Prevezer, 2007). With respect to the proportion of researchers out of total employment, in 2006 China stood at 1 per 1,000, remaining well behind the US with 9 per 1,000 or OECD with 7 per 1000 and Taiwan with 8 per 1,000 (OECD, 2007). Thus, scientific research has been increasing dramatically, but China remains well behind the US and Taiwan in terms of leading edge research.

The OECD's review of innovation policy in China pointed to notable deficiencies compared with developed markets, such as the immaturity of the institutional architecture of its national innovation system. In particular, it highlighted insufficient interaction among actors such as business enterprises, public research organizations, and various parts and layers of the government. This is in contrast to Taiwan, where ITRI in particular has emphasized the creation of innovation networks for technological diffusion with public research institutes assimilating advanced technologies from abroad, diffusing them to local enterprises, and serving as coordinating nodes to promote technological enhancement. There has also been a focus on localizing innovative potential in Taiwan through the science park with ITRI located in the Hsinchu Science Park, created on the Stanford model, and co-located in proximity to two universities. Government policy in Taiwan has also driven the creation of a local venture capital industry, with the number of venture capital firms rising from 76 in 1997 to 259 in 2004 (Dodgson, 2009).

The OECD's (2007) assessment of China's innovation capacity pointed to a shortage of complementary assets, such as advanced specialized infrastructure in particular areas of science and technology (OECD, 2007 p.17). It also highlighted the lack of formative ingredients that have sustained the creation of innovative clusters of high technological expertise in the US, such as an indigenous venture capital industry, the capability and infrastructure needed to launch IPOs, and appropriate managerial expertise for new ventures. Owen-Smith and Powell (2004) and Sorenson and Stuart (2001) in looking at the institutional origins of networks in the biotechnology industry discuss the importance of intermediaries, such as venture capital companies, in facilitating connections among nodes. This infrastructure with coordinating and intermediating functions has been absent in China, with very little domestic venture capital and few networking governance institutions.

Another feature pointed out by the OECD's report is the relatively weak enforcement of IPR in China. Despite signing up to TRIPS in 2001, infringement of IPR is commonplace in China. This is largely due to poor enforcement of IPR regulations due to lack of infrastructure and mechanisms for such enforcement (OECD, 2007). This article argues that this lack has negatively affected China's willingness to undertake proprietary forms of network construction that can exert control over leakages of proprietary information.

Another notable feature of the NIS in China's technological development has been the role of foreign companies through FDI and the locating of R&D laboratories in China (Athreye and

Prevezer, 2007). The R&D activity of MNCs used to be thought of as highly localized, in close proximity to the MNC headquarters due to the transferability of tacit technological knowledge, the need for coordination, the liability of foreignness, and the costs of distance (Patel and Pavitt 1991). However, more recently, it has been shown that US, UK and German MNCs in particular have been spreading their R&D activities to Asia, especially to China and India (UNCTAD, 1998; Beausang, 2004). Motivations for this internationalization of R&D include lowering costs for routine R&D operations, developing links with host countries where subsidiaries are established in order to enhance the knowledge bases at home, and to capture potential knowledge spillovers through links with local universities and research institutes with innovative competencies. The availability of scientific labor in China and India is also cited as a motive for the offshoring of R&D (Lewin et al., 2007).

Section 4. China's inventor network: Data and methods

There is an emerging literature on inventor networks (co-patenting or co-authorship of patents) regarded as a mechanism by which knowledge is transferred across geographic, social, and scientific distances (Trajtenberg et al., 2006; Singh, 2005, Breschi and Lissoni, 2004; Ejermo and Karlsson, 2004). We study the interplay over time of geographic and social distances within China's inventor networks that include teams of scientists and technologists working together on individual patents. Our analysis of distances examines the tendency toward geographic clustering, the degree of internationalization of knowledge flows through the location of inventors and assignees in foreign countries, and the structure and evolution of the social network underlying China's innovative activities.

The idea of using patents to study the social collaborative structure of knowledge transfer and creation was proposed by a number of empirical studies (Ahuja, 2000; Fleming et al., 2007; Singh, 2005). For example, Breschi and Lissoni (2004) argued for the use of co-inventors in the construction of social networks on the grounds that one can assume that inventors listed on the same patent know each other and have exchanged key technical information. The creation of interconnected patenting teams is therefore one way in which Chinese scientists have access to, and benefit from, the knowledge of research programs within various geographic regions of China as well as in more advanced countries. This takes place through the establishment of a social network in which scientific knowledge flows among inventors from different locations. For instance, patenting teams may span across international boundaries, with some inventors based in the US working together on a joint project with other inventors based in China. Moreover, the owners of patents might be based in the US, Europe or Taiwan and China. And they might be companies, universities or government. Our empirical domain therefore offers us the ingredients for the study of how the needs for knowledge combine with institutional constraints to affect the balance between geographic clustering and the construction of an internationally driven social network.

4.2 The data

Our data consists of a sample of 3,751 Chinese patents obtained from the US Patent Office between 1976 and 2006. A patent is classified as Chinese if at least one member of the team of inventors working on it is based in China. All patents are taken by application date rather than issue date. This is common practice in the literature as the application date represents the time at which the research leading to the patent was actually completed (Trajtenberg et al 2006; Owen-Smith and Powell, 2004). For each of the patents, we have collected information about its technological class, the inventors involved and the assignee that owns it. Our data also includes the geographic location of inventors as well as the institutional status (companies, universities, individuals, and government) and location of assignees. With respect to the technological class, the US Patent Office has developed a classification of over 400 main patent classes and 36 sub-categories. Based on this classification, we use the six main categories of patents as developed by Hall et al. (2001): Computers and Communications, Electrical and Electronics, Drugs and Medical, Chemical, Mechanical and Others.

We can obtain a broad overview of some geographic indicators of the patents by distinguishing between local inventor teams, where all members are located within China (further distinguished between being located in Beijing, in Shanghai, in China but not in Beijing or Shanghai, or a mix of those locations), and international teams which have at least one member located outside China. We have identified teams with members in North America (US and Canada), in the Asia-Pacific region (Australia, Hong Kong, Japan, Korea, Malaysia, Philippines, Singapore, Taiwan) and in other countries (when members are based elsewhere or in more than one of the previous international groupings). Table 1 shows these indicators for the periods 1986-95 and 1996-2006.

INSERT TABLE 1 ABOUT HERE

In addition, we have an overview of how local and international patents can be further classified in terms of geographic locations and institutional profile (companies, government, universities, individuals, unclassified) of their assignees, as well as technological field (chemicals, computers and communications, drugs and medical, electrical and electronic, mechanical, other). This helps assess whether local or international teams are more heavily represented in certain technological fields or in certain institutional categories.

Table 2 clearly shows the geographic clustering of inventor teams, with a fair proportion of teams locally based in Beijing and Shanghai and with twice as many teams wholly based in China (2,360) as international teams with members outside China (1,391). Alongside this, there have been a growing number of teams with international members based in the Asia-Pacific countries. In terms of geography of the assignees and their proximity to their inventor teams, local teams are owned more by Chinese assignees with a sizable grouping in Beijing. International teams tend to be owned by US assignees or by Asia-Pacific assignees.

INSERT TABLE 2 ABOUT HERE

Regarding the technological field, local teams tend to operate within electrical and electronic fields. International teams are also in electronics as well as in the computer and communications field. Traditional technologies (mechanical, chemical and others) are slightly more represented by local teams. Over the two periods, there has been an increase in patents in the newer technological fields (computers and communications, and electrical and electronic) and a marked growth in the proportion of international teams in those two technological fields.

4.3 Methods

We construct a number of geographic measures to examine co-location of inventors within and between patent teams, and their evolution over time. By drawing on the geographic location of inventors and firms, we measure geographic distances between them. We measure geographic distance *within* patents using the location of each inventor working on a patent and taking the average distance between each inventor and all other members of the patent. To test for robustness, we use three measures of distance within patents. First, the mean distance between inventors on a patent is calculated by taking the geographic coordinates of every inventor working on a patent, summing the distances between all pairs of inventor, and dividing by the number of distances on the patent. Second, we use the median distance which discounts outliers (extreme values of distances) in the team. Finally, we measured the shortest path within patents calculated by summing the shortest distance connecting every inventor to others on a patent without repeating inventors, and dividing by the length (i.e., number of connections) of the path (Wasserman and Faust 1994).

Geographic distance *between* inventors on different patents is measured by looking at the average proportion of inventors that are located within a set radius. By increasing the radius, we were able to measure the proportion of inventors located in the same city, region and, ultimately, country. This allows us to uncover the tendency of inventors, even when they belong to different teams, to operate in proximity to one another, and thus create agglomerations of various geographic boundaries.

The geographic distances between inventors and assignees are also calculated in two ways: as mean and minimum distances between inventors working on patents and the assignees of those patents. All distances are measured on a logarithmic scale to discount longer distances to a greater extent than shorter ones, based on the fact that the costs of collaboration do not increase linearly over geographic space (Sorenson and Stuart, 2001).

We also mapped the dynamic social network connecting inventors to study the structure and evolution of social interaction over time. Our network consists of the links that are established between inventors if they have collaborated on the same patent. Knowledge is assumed to flow between patents through the inventors that work on those patents. For each year, we constructed the one-mode network projection of the two-mode network where inventors are associated to patents (Wasserman and Faust, 1994). These networks are cumulative in that, for each year, they reflect how inventors have interacted with one another since the beginning of the observation period until that year[1].

We examine two network measures over time. First, we study the evolution of network connectedness by measuring over time the size of the giant component. This is defined as the largest set of inventors in the network that can be reached from other inventors through some path (Barrat et al. 2008; Dorogovtsev and Mendes, 2003). Second, we measured the average geodesic distance between inventors. which is the mean of the smallest number of ties between every reachable pair of inventors in the network representing the shortest distance between any two randomly selected inventors (Wasserman and Faust 1994)

Section 5. Results

This section first reports results on geographic distances in China's inventor network. This is organized into three parts: distances among inventors within the same team; distances between different teams; and distances between inventors and assignees. The section concludes with the study of the social network connecting inventors, with an emphasis on connectedness and the emergence of a giant component, and the distances that separate inventors.

5.1 Geographic distances among inventors within teams

We address the following question: To what extent do inventors that belong to the same patent tend to be geographically clustered, and do university- and company-owned patents differ in this respect? Figure 1 shows that there was an increasing trend up to the mid-1990s in the geographic distances between inventors within the same patent team, followed by a slightly decreasing trend. All measures we used for this geographic distance show consistent results.

INSERT FIGURE 1 ABOUT HERE

We also controlled for the effects of internationalization, and limited our analysis of distances only to local patent teams in which all inventors were based in China. Results remain consistent, with decreasing distances since the mid-1990s, thus suggesting that inventors working on the same team tend to be geographically concentrated.

We further distinguished between company-owned and university-owned patents, and found that the decreasing trend (since the mid-1990s) of distances within inventor teams characterizes only company-owned patents (Figure 2a), but not those with university assignees (Figure 2b).[2]

INSERT FIGURE 2 ABOUT HERE

5.2 Geographic distances among inventors between teams

The observation that inventors working on the same patent teams tend to become geographically concentrated leads us to investigate whether this tendency can also be detected for inventors working in different teams. We therefore ask the following question: What is the geographic distance separating inventors that belong to different patent teams?

The geographic distance proposed to define the boundaries of clusters tends to vary in the literature. For example, Jaffe et al. (1993) have suggested distances based on US states and metropolitan areas; Cooke and Clifton 2004 have argued for interpretation of spatial distance to be related to varying spatial and institutional factors. . In our analysis, we study the agglomeration tendency within a radius of 80 km, being the smallest distance within which there is an increasing trend over time of the proportion of inventors that are co-located. Above this radius and up to 200 km, results remain consistent. Above 200 km, distances become too large to detect these agglomeration tendencies. As Figure 4 indicates, Chinese inventors from different patents tend to agglomerate within geographic boundaries with radiuses ranging from 80 km to 200 km.[3]

INSERT FIGURE 3 ABOUT HERE

5.3 Geographic distances between inventors and assignees

Tendencies toward clustering or internationalization can also be studied by looking at the locations of assignees. We ask the following question: To what extent are inventors and assignees geographically co-located? Figure 4 shows a trend of increasing distances between inventors and their assignees throughout the observation period. This holds for both companies or universities as assignees. Results remain consistent when both average and minimum distances are used.[4]

INSERT FIGURE 4 ABOUT HERE

Table 3 corroborates our results, showing that the leading assignees of Chinese patents include international companies. For example, the company that owns the largest number of patents is from Taiwan. There is therefore some evidence in support of internationalization tendencies, in that an increasing number of teams not only are composed of international inventors (see Table 1), but they are owned by international assignees located at increasing geographic distances from the inventors. This finding therefore points to the complexity of the dynamics of China's innovative activity, whereby a tendency toward the internationalization of assignees co-exists with the countervailing tendency toward geographic co-localization of inventors within the same patent teams (especially those that are company-owned) as well as of inventors working in different teams.

INSERT TABLE 3 ABOUT HERE

5.4 The inventor network: Giant component and social distances

Table 4 shows the descriptive statistics of the inventor network and their evolution throughout the observation period. Results show that the size of the network grows rapidly, with an increasing rate of growth in number of inventors over the years. A striking finding is that the ratio between the size of the giant component and the size of the whole network remains small throughout the entire period. The result suggests that inventors have a tendency to work in relatively small connected groups, without interacting with other inventors that belong to different groups.

INSERT TABLE 4 ABOUT HERE

To discount for the possible effects of randomness and test if this property actually signals a genuine organizing principle of the inventor network, we compared the size of the giant component that was found in the real network to the size of the giant component that would occur in a network in which ties between inventors are placed at random.[5] As shown in Table 4, in all corresponding random networks, many more inventors than in the real ones are part of the giant component. If ties were forged at random, ties between inventors would be more evenly distributed across the networks, and there would not be the fractures between groups that we found in reality.

A graphical presentation of network connectedness and size of the giant component over time is offered by Table 5. The table shows the inventors included in the whole network and in the giant component for 1986, 1997, 1998 and 2004. Note that in 1986 there is no clear giant component: there are multiple disconnected patents with identical size representing the maximum size of a connected component that can be found in the network. In 1997, one clearly identifiable giant component connecting inventors from different patents emerges. However, there is competition among disconnected components over which component will absorb the largest portion of the network. This becomes more evident in 1998, when the giant component includes inventors that are all different from those of the giant component in 1997 . One striking feature of the structure of the giant component in 1998 is the role played by few inventors in bringing the component together. These inventors act as cut-points that bridge otherwise disconnected groups of inventors (Wasserman and Faust, 1994). This structure is further emphasized in 2004, where more inventors join those that already belonged to the giant component in 1998 , and where a few inventors hold the component together by intermediating between groups.

INSERT TABLE 5 ABOUT HERE

The last two columns of Table 4 refer to the network average geodesic distance. The observed average geodesic distance is increasing over time. Inventors need to rely on longer chains of interconnections if they want to reach others. Thus, they devote time and energy to create ties more locally than globally, and tend not to build long-range short-cuts that would bring together otherwise disconnected groups.

Section 6. Discussion and conclusion

This article has adopted a combined geographic and network perspective to examine the spatial distribution and social embeddedness of China's inventors working on patent teams. The main focus was on the interplay among different measures of geographic and social proximity. We uncovered mixed tendencies toward both geographic co-location and dispersion. Results provide empirical support in favor of the geographic clustering of inventors, especially those belonging to the group of company-owned patents. Tendencies toward agglomeration were also found to affect scientists not working on the same patents. Co-location, however, occurs alongside the formation of extra-cluster linkages leading to greater geographic distances between inventors on university-owned patent teams as well as between inventors and their assignees. The article also calls into question the relationship between geographic and network measures of proximity. Results showed that there is no straightforward relationship, such as one of substitution, between decreasing (increasing) social distance, with increasing social inter-connectedness or embeddedness, and increasing (decreasing) geographic distance. Instead, as the social network evolves initially through an increasing number of disconnected groups of inventors, we found a pattern of increasing social distances, in conjunction with geographic distances that are both decreasing (e.g., for company-owned patents) and increasing (e.g., for university-owned patents). At the same time, we found that the network's giant component takes some years to emerge and increase in size. Thus, the network becomes more connected over time, mainly as a result of a few key bridging inventors that forge the links between different otherwise disconnected parts of the network.

Our study helps integrate and extend the longstanding literature on the salience of geographic clustering for innovative activities. A number of empirical studies have investigated the benefits of intra-cluster learning processes, but with only a limited emphasis on the advantages offered by the geographic dispersion obtained through extra-cluster linkages and long-range ties (Giuliani and Bell, 2005). In turn, social networks may have mixed effects on geographic distances. They can favor geographic concentration when social and professional relationships tend to cluster geographically (Stuart and Sorenson, 2003). But they can also favor geographic dispersion precisely when those ties are available only globally. Moreover, as our findings suggest, these tendencies are not mutually exclusive, but may co-exist within the same population of economic units with heterogeneous institutional profiles.

In addition to its theoretical contribution to the debate on geographic clustering, the article has practical implications for regional development and policy-making within the context of knowledge creation and transfer in China. The increasing tendency of knowledge creation and learning relationships to cluster in certain regions appears to apply in China as elsewhere (Prevezer and Tang 2006) . Beijing and Shanghai have grown as centers for scientific activity that, in turn, has failed to develop evenly throughout China. At the same time, China has witnessed the construction of an international network, made of global pipelines for innovation with connections to international companies and universities. But the weak capacity for network creation within

China has meant that there has been relatively weak connectivity within the network despite the increasing role of the linkages to international scientists and companies.

One of the key features of the US's NIS is its network-making capacity and the ability and propensity to construct dense regional networks using such institutions as venture capital companies to promote intermediating functions within these networks. The lack of such institutions appears to be one of the major weaknesses in China's NIS. The role of government policy in sustaining the creation of intermediating institutions (e.g., science parks and venture capital companies) has been documented in other countries, such as Taiwan. It is precisely this capacity for connectivity between isolated nodes of innovative activity that should be fostered by measures intended to strengthen China's innovation system.

Our results also highlight a sharp contrast between university-owned patents, with a pronounced tendency toward internationalization, and company-owned patents, with a tendency toward geographic clustering. This could be explained by China's institutional environment characterized by relatively weak IPR. From this perspective, companies have found it easier to control flows of proprietary information within geographically limited regions, whereas universities, typically characterized by more open regimes of information disclosure, have been able to transfer and exchange knowledge over longer distances. This is a conjecture, and further research is necessary to investigate whether issues of proprietary control are playing such a role in concentrating inventors working on company-owned patents within certain geographic areas.

Finally, we wish to highlight the limitations of our work and possible avenues for integrating the reported analyses. The main weakness is concerned with the data. Limiting the sample to include only patents with at least one Chinese inventor affects the connectivity of the resulting social network. For example, in our network there may be no path connecting two Chinese inventors when in fact they may well be indirectly connected through two co-inventors that have worked on a non-Chinese patent. A more comprehensive dataset including also non-Chinese patents would enable the construction of a more accurate network among Chinese inventors in which such indirect ties would be apparent. A more detailed network analysis, for instance by partitioning the network into technological and institutional categories, would allow for a more instructive comparison between topological and geographic measures. However, the sparseness of the data has not enabled us to partition the network based on the properties of the nodes. Finally, we took a macro perspective in the assessment of distances, unlike other works that have instead used node-level measures to examine the impact of the network on geographic distances (e.g., Sorenson and Stuart, 2001). Integrating these two lines of research would enhance our understanding of the relationship between geographic and network distances, as well as their combined effects on learning processes and knowledge creation.

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Team	1986-1995	1996-2004
Beijing	116 (16.5%; 16.5%)	373 (12.5%; 12.5%)
Shanghai	48 (6.8%; 23.3%)	175 (5.9%; 18.3%)
Other Chinese	292 (41.5%; 64.8%)	1,265 (42.3%; 60.6%)
Mix of Chinese categories	14 (2.0%; 66.8%)	51 (1.7%; 62.3%)
Asia Pacific	43 (6.1%; 72.9%)	411 (13.7%; 76.0%)
US and Canada	144 (20.5%; 93.3%)	555 (18.5%; 94.6%)
Other countries	26 (3.7%; 97.0%)	78 (2.6%; 97.2%)
Mix of International categories	21 (3%; 100%)	85 (2.8%; 100%)
Total	704	2993

Table 1: Number of patents (with percent and cumulative percent in parentheses) for different geographic categories.

	1986-1995		1996-2004	
	local teams	Int'l teams	local teams	Int'l teams
By assignee location				
Chinese assignees	225 (48%)	18 (8%)	677 (36%)	57 (5%)
- based in Beijing	77	6	206	6
- based in Shanghai	19	0	85	5
Asia-Pacific assignees	33 (7%)	24 (10%)	467 (25%)	377 (33%)
US and Canadian assignees	19 (4%)	140 (60%)	248 (13%)	537 (48%)
Other assignees	10 (2%)	26 (11%)	44 (2%)	88 (8%)
Unclassified assignee	183 (39%)	26 (11%)	428 (23%)	70 (6%)
By institutional type of assignee				
Company	129 (27%)	112 (48%)	1,198 (64%)	921 (82%)
University/PRO	131 (28%)	77 (33%)	168 (9%)	119 (11%)
Government	1 (0%)	13 (6%)	2 (0%)	9 (1%)
Unassigned/Individuals	209 (44%)	32 (14%)	496 (27%)	80 (7%)
By primary technological field				
Chemicals	120 (26%)	91 (39%)	263 (14%)	176 (16%)
Computers and communications	27 (6%)	14 (6%)	230 (12%)	266 (24%)
Drugs and medical	65 (14%)	49 (21%)	183 (10%)	137 (12%)
Electrical and electronic	79 (17%)	43 (18%)	634 (34%)	309 (27%)
Mechanical	98 (21%)	20 (9%)	238 (13%)	81 (7%)
Other	81 (17%)	17 (7%)	316 (17%)	166 (14%)

Table 2: Classification of local (all inventors within China) and international (involving inventors outside China) patents in terms of the geographic locations of assignee, institutional type of assignee and technological field.

Top 10 Assignees	Number of Patents	Location of Assignee
Hon Hai Precision Industries. Co., Ltd.	495	Taipei, Taiwan
China Petroleum and Chemical Corporation	122	Beijing, China
Microsoft Corporation	95	Redmond, WA, USA
Inventec Corporation	58	Taipei, Taiwan
Tsinghua University	31	Beijiang, China
International Business Machines Corporation	29	Armonk, NY, USA
Foxconn Precision Components Co., Ltd.	28	Taipei Hsien, Taiwan
Winbond Electronics Corporation	26	Hsinchu, Taiwan
SAE Magnetics (H.K.) Ltd.	24	Kwai Chung, Hong Kong
Bayer Aktiengesellschaft	23	Leverkusen, Germany

Table 3: Top 10 assignees of Chinese patents and their locations.

Year	inventors	giant component	ratio of giant component over number of inventors	giant component in a corresponding random network	ratio between observed and random giant component	geodesic distance	geodesic distance on a corresponding random network[6]
1986	213	5	2.35%	14	34.65%	1.6	2.07
1987	294	5	1.70%	14	35.90%	1.6	2.01
1988	416	7	1.68%	28	25.26%	1.19	2.77
1989	569	9	1.58%	36	24.71%	1.39	3.10
1990	668	9	1.35%	55	16.49%	1.39	3.40
1991	815	9	1.10%	45	19.84%	1.39	3.20
1992	969	9	0.93%	46	19.38%	1.39	3.38
1993	1,169	9	0.77%	69	12.96%	1.39	4.17
1994	1,354	9	0.66%	166	5.43%	1.39	6.17
1995	1,544	10	0.65%	315	3.17%	1.53	7.41
1996	1,763	11	0.62%	417	2.64%	1.58	8.56
1997	2,066	14	0.68%	714	1.96%	1.65	9.02
1998	2,447	46	1.88%	896	5.14%	4.23	9.36
1999	3,007	61	2.03%	1,262	4.83%	4.61	8.58
2000	3,642	83	2.28%	1,897	4.37%	4.19	7.77
2001	4,511	95	2.11%	2,559	3.71%	4.34	6.38
2002	5,366	166	3.09%	3,275	5.07%	5.96	6.09
2003	5,986	233	3.89%	3,812	6.11%	6.92	5.91
2004	6,307	245	3.88%	4,111	5.96%	7.01	5.79

Table 4: Descriptive statistics of the social network.

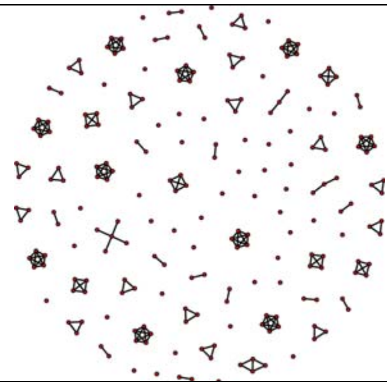
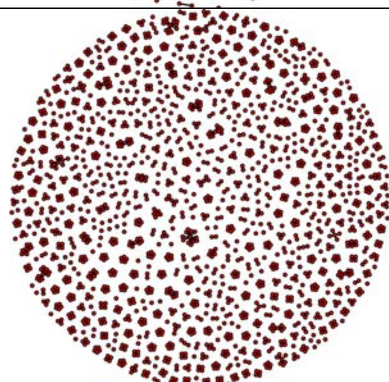
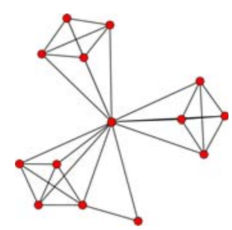
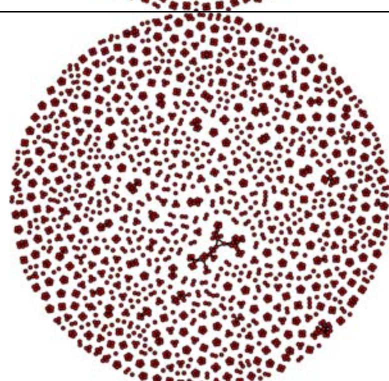
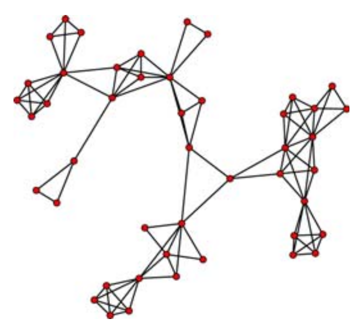
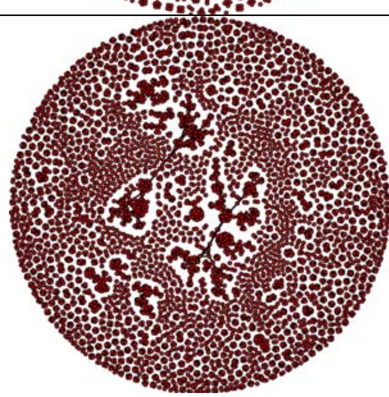
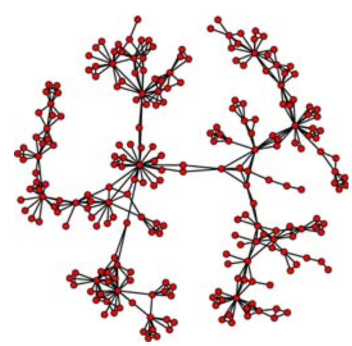
year	The entire inventor network	Giant component
1986		
1997		
1998		
2004		

Table 5: The inventor network and its giant component in 1986, 1997, 1998, and 2004.

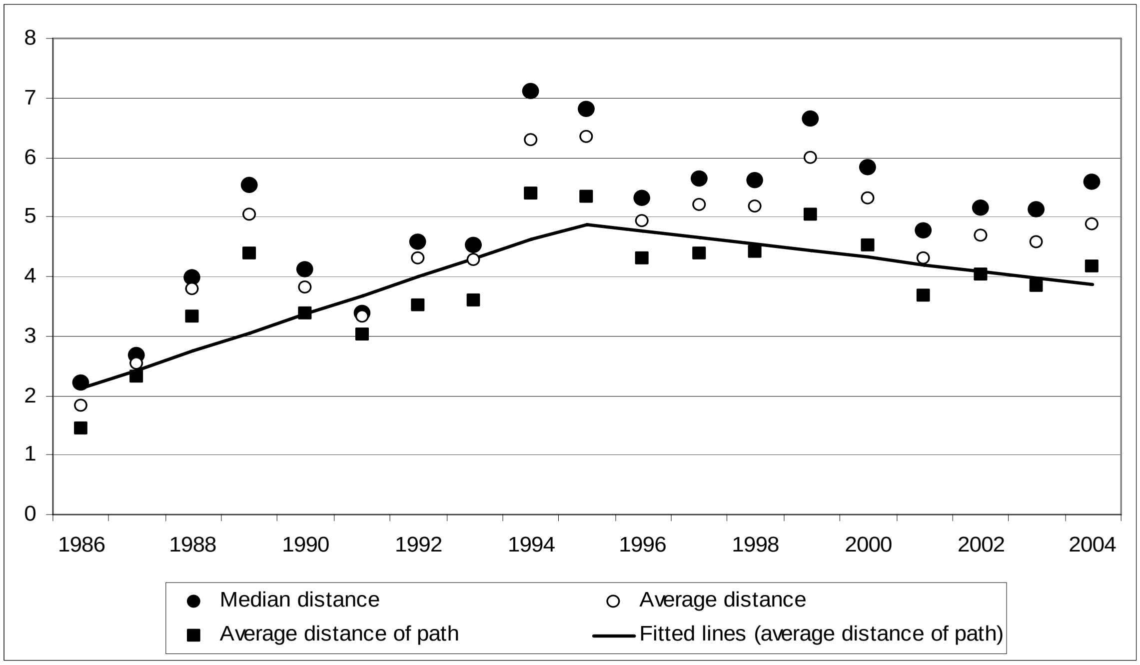


Figure 1: Geographic distance between inventors working on a patent.

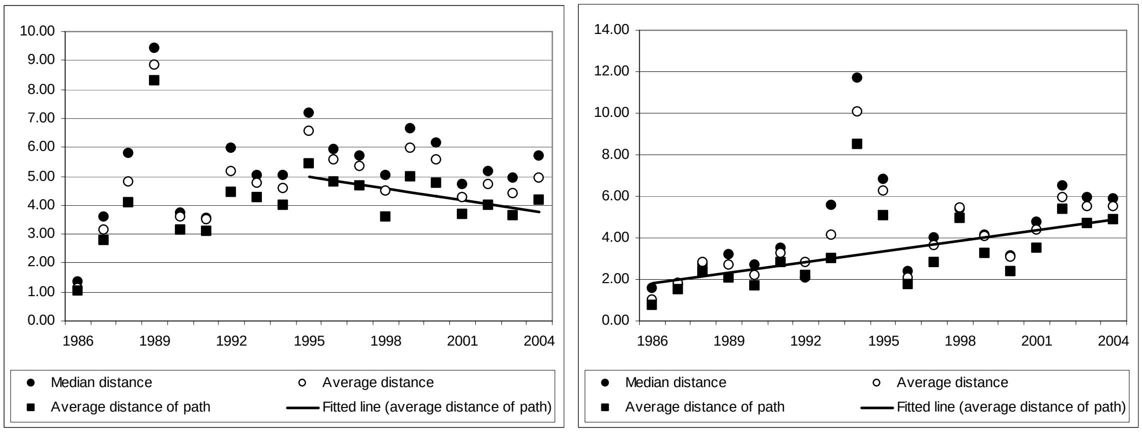


Figure 2: Geographic distances between inventors on patents owned by companies (a) and universities (b), respectively.

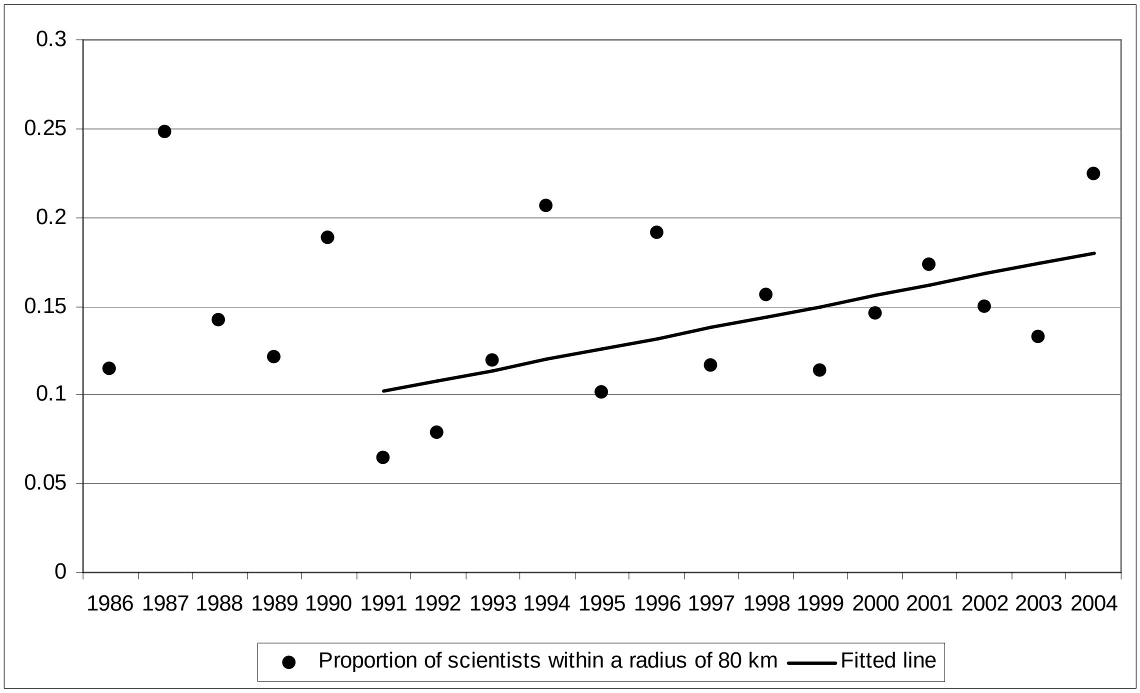


Figure 3: Geographic distances among Chinese inventors belonging to different patent teams.

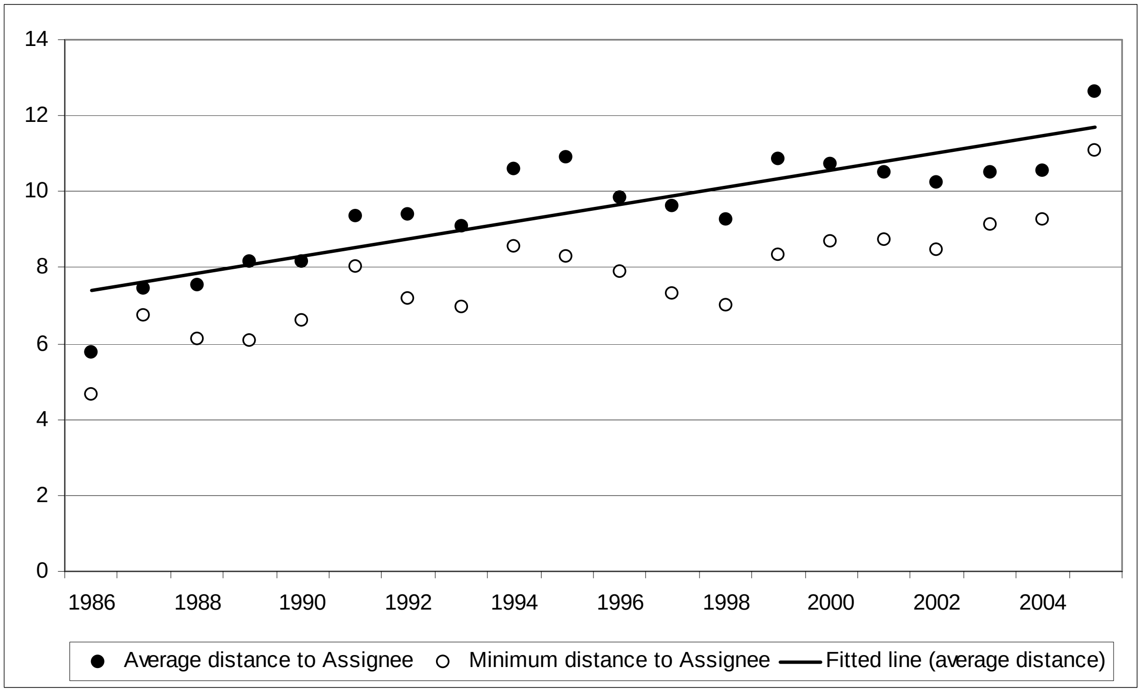


Figure 4 Geographic distances between inventors and their assignees.

Endnotes

[1] We were not able to construct separate networks by technological class due to lack of connections within the networks and hence the sparseness of the network data.

[2] The trend lines in the diagrams have the following statistics: a) -0.1369year + 278; $R^2 = 0.4136$; $p<0.045$; b) 0.1723year - 340; R2 = 0.2765; $p<0.021$.

[3] The regression line in Figure 3 has the following statistics: 0.006year - 11.9; R2 = 0.29; $p<0.047$.

[4] The regression line in Figure 4 has the following statistics: 0.209year - 407; R2 = 0.6903; $p<0.000$.

[5] To this end, for each year, we constructed a corresponding two-mode random network using the same number of patents and inventors as in our data. Each inventor was randomly assigned to as many patents as he or she actually worked on. From these two-mode random networks, we then obtained the one-mode projections in a similar fashion as before. We also tested for robustness by constructing random Bernoulli one-mode networks as well as random one-mode networks based on the same degree distributions as the real ones (Barrat et al., 2008; Dorogovtsev and Mendes, 2003). Results based on these random networks are consistent. Here we report only results based on the two-mode random networks as these reflect more closely the nature of our inventor networks.

[6] The geodesic on corresponding random networks is always larger and, since 2000, follows a different trend than the geodesic in the actual networks. This divergence, however, is to a great extent due to the fact that the size of the giant component on corresponding random networks is much larger than the size of the observed giant component.